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Automatic frequency control systems for reflex klystrons

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AUTOMATIC FREQUENCY CONTROL
SYSTEMS
FOR
REFLEX KLYSTRONS

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AUTOMATIC FREQUENCY CONTROL SYSTEMS
FOR REFLEX KLYSTRONS

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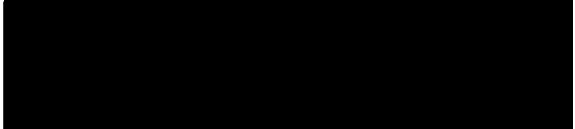
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Submitted in partial fulfillment
of the requirements
for the degree of
MASTER OF SCIENCE
in

ENGINEERING ELECTRONICS

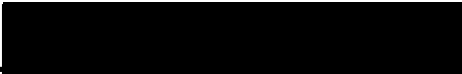
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11332

PREFACE

During the first three months of this year I was stationed at the Westinghouse Electric Corporation plant in Baltimore developing an AFC system for the SPS6 radar. My work consisted of building and testing the diode-transitron control circuit as well as the associated IF stage and discriminator.

I am indebted to Mr. D. N. Tashjian, section engineer, and to Mr. R. G. Broden, engineer, for assistance and suggestions while I was at Westinghouse. I am also indebted to Dr. W. P. Cunningham of the Postgraduate School for much good advice and assistance in preparing this thesis.

TABLE OF CONTENTS

Introduction	1
Methods of Frequency Changes	2
Causes of Frequency Changes	2
Methods of Tuning	2
Types of AFC	5
Difference Frequency Systems	7
General	7
Transmitter Sample	8
Mixers	10
IF Stages	11
Discriminators	11
Video Amplifiers	13
Control Circuits	13
General	13
Types of Control Circuits	16
DC Amplifier Control Circuit	16
Gas Discharge Tube Control Circuit	19
Diode-Transitron Control Circuit	24
Thermally Tuned Control Circuit	31
Absolute Frequency AFC	39
Electronically Tuned Control Circuit	39
Thermally Tuned Control Circuit	42

LIST OF ILLUSTRATIONS

- I Reflex-Klystron Characteristics
- II Block Diagram, AFC Systems
- III Spurious Signals
- IV Wrong Sideband Effect
- V DC Amplifier, Schematic
- VI Gas Discharge Tube AFC, Schematic
- VII Gas Discharge Tube AFC, Wave Forms
- VIII Diode-Transitron, Schematic
- IX Diode-Transitron, Wave Forms
- X Whitford AFC, Block Diagram
- XI Whitford AFC, Schematic
- XII Whitford AFC, Discriminator Characteristic
- XIII Absolute Frequency AFC, Block Diagram
- XIV Absolute Frequency AFC, Wave Forms
- XV Beacon AFC for 2K45

I INTRODUCTION

As the radio frequencies used in radars increased, it became more and more important to have some system in the set that would provide an automatic control of the frequency.

In the first place, the required bandwidth of the receiver is very important. Assuming a receiver bandwidth of two megacycles at a transmitter frequency of a thousand megacycles, a stability of two tenths of one per cent or one part in five hundred is required. However, if the frequency is increased to thirty thousand megacycles, this same bandwidth would require a stability of less than seven thousandths of one per cent or one part in fifteen thousand. Thus the allowable percentage change in the transmitter or local oscillator frequency is inversely proportional to the frequency and the required stability is more stringent with the higher frequencies of the present day radars.

In addition, the oscillators themselves are, in many cases, of low stability. This may be due to variable loads on the transmitter oscillator as the antenna rotates due to the reflections from objects close by, by internal thermal changes, or by changes in electrical conditions.

Finally, by nature of the use or position of the radar, such as in aircraft or missiles, it may be impossible to tune the system during operation.

For these reasons various types of automatic frequency control systems have been developed to fit the different systems in use.

II METHODS OF FREQUENCY CHANGES

1. Causes of frequency changes

At the present time there are three types of tubes that are used in radar microwave oscillators. They are magnetrons, klystrons and lighthouse tubes.

In all three types there are three methods of changing the frequency. The first method is by changing the geometric dimensions in the tube. In the magnetron there are tunable cavities which are actually part of the tube whereas in lighthouse tubes the cavity is in an external circuit. In klystrons, it may be either but is usually part of the tube itself.

The second type of frequency change is brought about by pulling factors in which reactance is coupled to the oscillator circuits from the load. The pulling figure of an oscillator is defined as the maximum change in frequency when a load having a voltage standing wave ratio of one point five is presented in all possible phases to the tube. The load on a radar transmitter can vary considerably as the antenna rotates and therefore change the reactance of the load and thus the frequency.

The third frequency changing factor is the pushing factor or electronic tuning factor in which reactance is introduced by changes in electrical conditions such as voltage current or magnetic field. Poor power supply regulation may produce changes that will change the frequency of the oscillator.

2. Methods of tuning

Corresponding to the three factors that produce frequency changes, there are three methods of tuning local oscillators. First geometric tuning can be accomplished by changing cavity dimensions by manual means or by thermal changes. Pulling control can be accomplished by means of reactance tubes or by a stabilizing cavity. Lastly pushing control may be used by changing voltages applied to the tube.

Geometric control is easier to apply to magnetrons and to thermally tuned klystrons than to lighthouse tubes. With lighthouse tubes there is usually more than one tuned circuit and therefore an automatic frequency control of lighthouse tubes would be very difficult to develop which could be applied to all circuits. Without tuning all circuits, a serious loss in output would result. In normal reflex klystrons, geometric tuning could be used but it would have the same drawback as with the magnetron, the control is relatively slow in being applied.

Pulling control is normally used at lower frequencies than are used in radars and usually is applied in the form of reactance tubes.

The third method, electronic tuning has the advantage that it is practically instantaneous. Due to the construction of a magnetron, it is difficult to apply to this type of tube. A lighthouse tube suffers, as a small change in electronic factors will cause a serious deviation from optimum conditions.

With reflex klystrons, electronic tuning comes into

its own. The frequency of a klystron is changed very easily by changing the potentials applied to the accellerator or repeller. Of these two, a change in the repeller voltage has a much greater effect than a change in the accellerator voltage and therefore it is the method usually used.

Electronic tuning of a klystron also has the advantage that very little change in the output power occurs with a relatively large change in the frequency. Figure I shows the output power and frequency changes as the repeller of a reflex-klystron is varied, other parameters remaining the same.

III TYPES OF AFC

Automatic frequency control systems may be classified in a number of ways. First they may be classified as to the frequency to be controlled. Under this heading are difference frequency systems and absolute frequency systems. In a difference frequency system the transmitter frequency and the local oscillator frequency are mixed together and the difference frequency or IF is maintained constant by controlling either the transmitter or local oscillator frequency. Usually the local oscillator frequency is the one which is controlled.

The second type or absolute frequency system is one in which the local oscillator is maintained at a fixed frequency.

A second method of classification of automatic frequency control systems is whether they are hunting or non-hunting systems. In a hunting system, the local oscillator is swept over a large range of frequencies in order to find the correct frequency. In a non-hunting system the local oscillator is tuned manually to a frequency very close to the desired frequency until the automatic features will take over and lock on the proper frequency. Once locked in, the system will remain locked over a much larger frequency range.

A final method of classifying automatic frequency systems is as to the type of tubes used for the control. This method will classify the systems as either hard tube or gas tube AFC systems.

Usually a given system may be classified under all three

of the above headings. It may be a hard tube difference frequency non-hunting type for example, or perhaps an absolute frequency gas tube hunting type.

The type of system of automatic frequency control that is used depends to some extent upon the set on which it is to be used. For instance, in a broadcast receiver where many stations must be tuned, an absolute frequency system could not be used and a difference frequency automatic frequency control system would be in order. Similarly in a radar set the transmitter and the local oscillator are close at hand and a difference frequency system may be used. If it is known that either or both the transmitter or local oscillator will drift in frequency, a difference frequency system should be used. On the other hand in a beacon receiver the transmitter frequency is not present therefore an absolute frequency control is required.

Before a hunting system can be used two requirements must be met. First there must be no possibility of the local oscillator locking on the wrong sideband.

Second, if the frequency drifts in the system are small compared with the receiver bandwidth, a hunting system is not required. However, a hunting system is very useful if the frequency drifts are large.

IV DIFFERENCE FREQUENCY SYSTEMS

1. General

More development has been done on difference frequency hunting and non-hunting automatic frequency control systems as these are the types used in pulsed radars to-day. Therefore, this type of AFC will be discussed first.

A block diagram showing the basic parts of difference frequency AFC system is shown in figure II. In this system a sample of the transmitted pulse and the local oscillator frequency are fed to a mixer and the output at the intermediate frequency, IF, is amplified and applied to a discriminator. The output of the discriminator is then an error voltage whose polarity depends on whether the intermediate frequency is above or below the crossover frequency of the discriminator and whose amplitude is proportional to the amount the IF is away from crossover. At crossover the amplitude of the error voltage is zero.

The discriminator error voltage is amplified and fed to the control circuit, the function of which is to convert it to a control voltage which is suitable for changing the local oscillator frequency in the proper direction. The polarities are such that any change away from the proper intermediate frequency will produce a control voltage which will return the intermediate frequency to its correct value.

As these systems require a finite error voltage to operate, there will be a difference in frequency between the intermediate frequency and the crossover frequency. In

order to have the correct receiver intermediate frequency, the discriminator crossover frequency is then shifted by an amount which will give the correct value.

2. Transmitter sample

In a radar set the transmitter is close to the receiver and the local oscillator. It would seem at first that this would simplify the AFC problem as the transmitter sample is readily available. However, because of the excessive radio frequency power levels present, this condition actually adds a number of new problems which have to be solved.

From previous work with pulsed radar systems it has been observed that many failures in AFC systems are due to improper size and shape of the transmitter sample.

In the normal video pulse there will be energy components at the intermediate frequency. This energy is, however, well below the normal IF level. If the pulse is overloaded, these energy components will be increased. There will then be large amounts of energy at the intermediate frequency which may exceed the desired level and produce a continuous error voltage. This spurious error voltage is produced by shock excitation of the IF circuit and is known as video hash.

Sometimes in the output from the crystal there are found frequencies which are multiples of the difference, between the local oscillator and transmitter frequencies. These frequencies are called harmonic hash and may be caused by beating between harmonics of the transmitter and local

oscillator or they may be caused by non-linearity in the mixer crystal.

Figure III shows these two types of spurious signals as well as the desired signal.

These two spurious signals increase in importance as the transmitter sample is increased and will be very troublesome if the RF power at the AFC crystal exceeds a few milliwatts. At these levels, the desired signals increase but slowly and the spurious signals are well below the level of the desired signal. Below these levels the spurious signal decreases slowly but leakage soon becomes intolerable and extra IF gain is needed.

For these reasons it is necessary to control accurately the gain of the system through the discriminator. If the gain is too high, the spurious signals would cause locking completely out of the band. If the gain is too low, if locking occurs at all, it will be near the peak of the discriminator curve and well away from crossover.

Leakage is another factor that will cause trouble in automatic frequency control systems. There are two sources of leakage. First, it is due to bad joints in the back of crystals and in choke joints. Second, leakage can be due to inadequate cross attenuation which allows TR box leakage power to reach the crystal. When it is realized that the power in the transmission line may be as high as one megawatt while the amount needed at the crystal may be less than one milliwatt, about a ninety six db difference, it

can readily be seen that leakage is very important.

3. Mixers

In the first radar sets a single mixer was used and a very simple circuit followed. In this form the single mixer has three serious drawbacks. First, the power reaching the crystal from the transmitter will be too high and spurious signals will result caused by shock excitation. Secondly, there is a spike on the transmitter sample which generates transients. The spike is caused by energy getting past the TR tube before it has a chance to fire. In addition, any harmonic energy present will get by the TR tube in the fired position and cause spurious signals as previously mentioned. The third drawback is that the system may be controlled by video information reaching the antenna between pulses of the transmitter. These signals would then produce control information which would be in error. Under this condition, the system could lock on to the wrong transmitter as the result of enemy jamming or accidentally from a nearby friendly transmitter.

Some of these difficulties may be overcome by elaborate circuits but others cannot be remedied with a single mixer system. For this reason many new designs have shifted to the double mixer or separate channel AFC system.

In this type, the sample of the transmitted pulse is taken out of the wave guide and attenuated down to the desired level. This gives a spike free pulse that is used to drive a separate IF amplifier. The level of the pulse

can also be adjusted to the optimum value.

Because of the high attenuation from the wave guide to the separate IF channel, reflections from targets are also attenuated and are negligible in giving spurious control information.

Trouble from harmonics as previously discussed can be eliminated by the use of a balanced mixer which will cancel out the even harmonics. The odd harmonics of the third and higher orders are usually negligibly small.

4. IF stages

The average output at the mixer crystal is usually too small to drive a discriminator properly so one or more IF stages are required. In these stages it is the usual practice to have the bandwidth of the IF stages wider than the peak to peak separation of the discriminator. This will allow the crossover frequency of the discriminator to be adjusted as necessary without any adjustments required on the IF strip.

Symmetry in the IF strip is much more important in the AFC circuit than in the signal channel. The IF spectrum of a short pulse has sideband energy on both sides of the center frequency. Therefore, if the IF amplifier is not symmetrical, these sidebands will not be cancelled out at crossover and depending on the circuit may produce wrong control information in the control circuit.

5. Discriminators

The discriminators used in difference frequency AFC

systems are conventional and very little need be said about them. The peak to peak separation of the discriminator should, however, be close to the receiver IF bandwidth in order that the control circuit will not allow the receiver IF to become detuned too much. The peak to peak separation being equal to the receiver bandwidth, it is determined by the pulse length used in the radar transmitter.

One difficulty that may be encountered in the discriminator circuit may be the presence of pickup and hum in the output. If the signal is small from the discriminator, these unwanted variations may be large enough to cause the control circuit to lock on the wrong frequency. To overcome this fault, the output from the discriminator should be at least one volt and preferably larger.

Another means of reducing the effects of hum with diode detectors in the discriminator is to raise the DC level of the output to around ten volts. To do this, instead of grounding the lower side of the discriminator, it should be connected to a positive voltage source. With this system the bias on the following video amplifier will have to be readjusted to its proper point.

The load on the output of the discriminator has the effect of stretching the width of the pulses because of the shunt capacitance across the output. In some circuits this is unimportant but in most control circuits stretching is advantageous. In this type, control is determined by the energy in the pulses that reach the control circuit. With a

given amplitude of pulse the energy is proportional to the width of the pulse and therefore stretching aids in giving positive control.

6. Video Amplifiers

The video amplifiers are normal and have sufficient bandwidth to provide a well shaped output pulse.

7. Control circuits

a) General

The final stage of the automatic frequency control feedback link is the control circuit, the function of which, is to convert the error voltage into the control voltage which will alter the local oscillator frequency by the proper amount.

In the different types of control circuits available there are certain factors which must be considered. The first of these is the follow rate of the control circuit, that is, the rate at which the control circuit can change the local oscillator frequency with a change in the transmitter frequency.

With electronic control the change in local oscillator frequency with changes of control voltage is practically instantaneous. As there is no control information between pulses, the control circuits must hold the control voltage fairly constant between pulses when no error voltages are present. This is necessary in order that the system remain tuned so echoes may be received during this interval. In other words, the speed of operation cannot be made fast enough to correct changes within one pulse interval.

In the case of motor driven automatic frequency control

systems mechanical speeds and inertia will limit the follow rate and in thermally tuned systems, the thermal time constant of the tuning assembly will likewise limit the follow rate.

The second factor requiring consideration in control circuits is the control range through which the repeller voltage must be capable of being operated. In the first place, the circuit must operate between the half power points of the reflex-klystron mode. This would mean in a hunting system that the sweep of the repeller voltage generated by the control circuit must be great enough to cover the half power points of the tube for which it is designed. As this change of repeller voltage varies even for tubes of the same type, a factor of safety should be provided to cover all possibilities.

In addition, the center of the desired mode varies for different samples of the same tube so there must be a control to shift the center of the repeller voltage sweep.

The mechanical tuning adjustment of a reflex-klystron changes the frequency of the maximum power point in the mode as well as the repeller voltage corresponding to that maximum point. In order to have a nearly constant power output of the local oscillator with expected variations in the mechanical tuning, adjustment of the mechanical tuning should be such that maximum power is developed by the klystron when the klystron frequency is at the proper difference frequency from the mean transmitted frequency.

At this point any deviations from the transmitter frequency will have little effect on the crystal current in the AFC

and receiver mixers. As mentioned above, this change in mechanical tuning will shift the center of the desired mode relative to the repeller voltage and therefore allowance must be made to shift the center of the control voltage sweep to compensate for this.

The third factor in control circuits which must be considered is the elimination of the possibility of locking on the wrong sideband. The local oscillator may be tuned either above or below the transmitter frequency and the usual automatic control system will operate correctly at only one of these two settings. Figure IV shows the discriminator output voltage in solid lines and the local oscillator tuning voltage in dashed lines. Both are drawn as a function of the local oscillator frequency.

For correct action in an automatic frequency control system, a change in local oscillator frequency requires that the voltage change in the discriminator output must be such as to oppose the change in local oscillator frequency. In figure IV, the system would lock at A, C, and D but correct locking would occur only at A. At C and D the system would lock outside of the discriminator peak to peak interval and the receiver would be mistuned. At point B the feedback system is unstable and the local oscillator would be forced away from the point.

11332 In some tubes the electronic tuning range is such that it will not cover both discriminator curves (above and below the transmitter frequency). In this case the local oscillator

can be placed on the proper sideband by mechanical tuning and will not be able to lock on the wrong sideband. Also in hunting systems the same thing can be accomplished by reducing band of swept frequencies sufficiently to include only the proper sideband.

In other tubes the electronic tuning range is so broad that the local oscillator will operate over both sidebands. In this it would be necessary to change the intermediate frequency so that points A and B will lie outside of the electronic tuning range. Another possibility would be to mechanically tune the local oscillator until operation was on the side of the mode (figure I) and oscillations ceased somewhere between A and C. This method would not be too practical as the crystal current and consequently the gain would vary with frequency.

b) Types of control circuits

There are four distinct types of control circuits for use in difference frequency control systems for radars. The main differences among them are due to variation in the method of obtaining the correct average repeller voltage or variation of the tuning mechanism. These four types are the DC amplifier AFC, Gas discharge AFC, Diode-transitron AFC and Thermal AFC. Although there may be more than one circuit in each type only one of each will be discussed in detail in order to show the principles involved.

c) DC amplifier control circuit

The first type of AFC control circuit to be discussed

is the DC amplifier system. This type is a system of proportional control in which the correction voltage output is proportional to the error signal in the region between the discriminator peak frequencies. In this type of circuit, the IF frequency is not held exactly at the desired value but is held within the bandpass of the IF amplifier, the amount of error being proportional to the amount of error which would be present without the AFC system.

In order to determine the amount of this error it is necessary to investigate two design parameters. The first is the tuning coefficient T_0 and the second is the slope of the discriminator at crossover, D . T_0 is obtained by plotting the bias voltage of the amplifier tube against the resultant oscillator frequency and then taking the reciprocal of the slope of the curve. The units of T_0 will then be megacycles per second per volt. D is simply the slope of the discriminator in units of volts per megacycle per second. The feedback or error reduction factor is then

$$\frac{1}{1 - T_0 D} \quad *$$

As an example, if the value of the feedback factor is one fortieth, and without AFC the circuit would be ten megacycles out of tune, the AFC system will reduce this error to one forth of a megacycle.

The effect of drift in the transmitter or local oscillators uncorrected tuning is equivalent to a change in the mechanical

*See article 3.2 Microwave Receivers, McGraw-Hill, New York, 1948.

tuning of the local oscillator. Therefore there will be a reduction in the local oscillator power output as the peak of the mode is shifted away from the position of correct IF frequency as previously mentioned in the discussion on mechanical tuning adjustments.

An example of a DC amplifier AFC control circuit is shown in figure V. This circuit is taken from an airborne radar built by the Bell Telephone Laboratories. In this circuit a Weiss discriminator is used with Strandberg (anode bend) detectors in place of the usual diode detectors.

As the output from both detectors is negative, it is necessary to reverse the polarity of one of them in order to give the correct discriminator output. This is done by using a triode as a cathode follower and coupling the voltage by cathode follower into the DC amplifier.

Because of the 6800 micromicro farad plate condensers, most of the pulse integration takes place in the plate circuit. With input pulses the plate resistance of the detectors is reduced to a low value which permits the condensers to discharge rapidly for a short interval. Between pulses they recharge through the 4.7 megohm plate load resistors at a slower rate but for a longer time. The time constant for charge is 3.2×10^{-2} seconds and the interval between pulses is 2.5×10^{-2} seconds for the pulse repetition frequency used. Therefore, the condensers lose about half their charge between pulses, resulting in a ripple voltage on the plate of the amplifier tube.

An AFC system cannot have a large ripple on the frequency control voltage and therefore a filter consisting of the 1.8 megohm resistor and the .25 microfarad condenser are used to remove it. As discussed under factors controlling the follow rate, this filter will cause a great reduction in that rate.

In order to set the operating range to agree with the repeller voltage required for the oscillator mode, a 100K variable potentiometer is provided in the plate circuit of the DC amplifier.

In this type of AFC circuit, the operation is very dependable but the output repeller voltage wave form is a compromise between the need to have a constant voltage and the need to have a fast follow rate.

d) Gas discharge control circuit

In this type of circuit a different control principle is used from the proportional control of the DC amplifier AFC. The gas discharge type is an example of the frequency control principle. In this type, the control voltage, which is applied to the repeller of the reflex klystron, is determined by the frequency with which a search stopping tube is fired (V_1 in figure VI). The control voltage is also independent of the amplitude of the firing trigger as long as it is greater than the threshold value necessary to fire the tube as determined by the bias on the search stopping tube.

The gas tube control circuit can also be called a drift-in type of control. It is called this because it continually

tries to change the control voltage in one direction and the error voltage applied to the circuit pushes it back beyond the correct value from which position it drifts back through the correct value again.

The circuit diagram and wave forms for a gas discharge type of control circuit is shown in figures VI and VII. The search tube, V_2 , is a sawtooth generator similar to the sweep circuits used in many cathode ray oscilloscopes. Normally the sawtooth wave period is from one tenth of a second to one second. In the circuit shown, the period is one half a second. This circuit is used by the Westinghouse Electric Corporation in a commercial marine radar manufactured by them.

With no error voltage from the discriminator, V_1 is biased below cutoff by means of the grid and cathode return potentials. V_2 , then, is free to operate as a sawtooth generator sweeping the repeller voltage of the reflex klystron across the frequency band.

At some position of the sweep on the repeller, the correct beat frequency will occur and pulses will come through the discriminator and be present on the grid of V_1 . V_2 will continue to sweep until a pulse has sufficient magnitude of the proper polarity (positive) to fire V_1 . At this point, the condenser C_1 discharges rapidly through the tube and lowers the plate potential of V_1 to a value approaching that of the cathode. When this plate potential reaches a level of from ten to twenty volts above the cathode potential, the arc in tube V_1 will be extinguished and the plate will rise expo-

nentially towards its former value close to the positive power supply level. The rate at which the plate rises is determined by the time constant R_1C_1 .

The plate will continue to rise until another pulse on its grid has sufficient magnitude to fire the tube again. Thus control is exercised on only a fraction of the total number of pulses, usually being one out of every three or four.

As previously mentioned, up to the time that V_1 fired, the plate of V_2 was rising and charging C_0 . Its plate potential then would be less than that of V_1 . However, when V_1 fires, its plate rapidly drops below that of V_2 and consequently the condenser C_0 will discharge through R_0 and the tube V_1 . This discharge of C_0 will then stop the repeller voltage rise and start it in a downward direction.

When the arc in tube V_1 is extinguished and the plate potential begins to rise again, there will be a time when the plate of V_1 is again greater than the plate of V_2 so C_0 will again start to charge. This recharging of C_2 will again cause the repeller voltage to rise producing a cup shaped wave form on the repeller.

The plate of V_2 will continue to rise until the klystron frequency sweeps back and produces a discriminator pulse large enough to fire V_1 again. It is apparent that repeller voltage will have a ripple on it even when the system is locked in.

This repple voltage has to be limited in magnitude as the frequency ripple in the local oscillator must be small compared

to the receiver bandwidth.

In limiting the ripple, however, the follow rate of the system is also reduced. This is due to the shunt condenser C_0 across the repeller. It is therefore necessary to compromise between the two desires of a good follow rate and a low ripple.

In this type of control circuit the follow rate will vary depending upon in which direction the change occurs. If the local oscillator is tuned to a position above the transmitter frequency and then the transmitter frequency increases, the effect will be to move down the discriminator characteristic toward crossover. This shift will continue down the curve until the amplitude of the pulses at the grid of V_1 is reduced below the threshold value and then V_1 will not fire.

Under these conditions the upward sweep of the repeller voltage will continue until the pulses again fire V_1 . This rise will be at the maximum rate allowable with the given time constant, $(R_1 + R_0)C_0$. As long as the frequency change remains within the limits of the control range, no matter how fast the change of frequency of the transmitter, the local oscillator will eventually catch up and lock in again at the proper frequency.

If the transmitter frequency change is too fast, the signals will be momentarily lost in the receiver but this time will usually be so short that it is not discernable. The limiting follow rate in this direction then will be set by the maximum

rate at which the frequency can be changed by the sawtooth generator, V_2 , alone.

In the other case, the transmitter frequency decreases so that the operation of the pulses moves up the discriminator characteristic curve and thus the individual pulses increase in magnitude. The pulses will continue to increase in amplitude until finally a pulse, which previously was too small, is now large enough to fire V_1 . The limit, of course, is when every transmitter pulse fires V_1 and C_0 is being discharged at its maximum rate.

If the rate of change of the transmitter frequency is too great, the pulses will move over the peak of the discriminator characteristic and then amplitude will decrease until they no longer are large enough to fire V_1 . At this point the system will become unlocked and the sweep will start again for one cycle.

The follow rate in this direction can be increased by increasing the pulse repetition frequency allowing V_1 to fire more frequently and therefore discharging C_0 at a more rapid rate.

Both the right and left follow rates could be increased by lowering the values of R_0 and C_0 but again this would result in a larger ripple voltage on the repeller when the system is locked in.

To allow for differences in the position of the mode relative to the repeller voltage a range set control, R_2 is provided. Changing this control sets the band of voltages over which the tube sweeps. This is accomplished by varying

the dc level of the grid and cathode and thus varying the point at which the arc in V_2 is extinguished.

The control range is adjusted by changing the bias on V_2 until the sawtooth voltage has the proper magnitude. By limiting this range to one mode or less, wrong sideband operation is eliminated.

In the design of the gas tube AFC control circuit R_1 should be made large enough so that the plate of V_1 will drop low enough when fired to extinguish the arc in V_1 . If R_1 is too large, the rise time of the plate of V_1 will be excessive and a larger ripple will result. In any case R_1C_1 should be very much smaller than R_0C_0 to reduce the ripple on the repeller.

In this respect the power supply voltages should be large within the limits of the gas tubes in order to increase the rate of rise of the plate voltages thus increasing the follow rates.

e) Diode-transitron control circuit

The diode-transitron circuit is a hard tube hunting type of AFC control circuit, which, when locked on the proper frequency, uses proportional control as does the DC amplifier system. In fact, the diode transitron might be called a hunting type DC amplifier system. The circuit diagram is shown in figure VIII.

The circuit consists of two sections; a transitron oscillator which generates the slow hunting sweep, and a diode detector which acts as a search stopper.

The transitron oscillator is a variation of the precision

ranging phantastron circuit * which is used in many radar indicators. The basis of its operation depends essentially upon the negative transconductance which exists between the suppressor grid, g_3 , and screen grid g_2 of a pentode. The plate wave form obtained with the transitron is identical with that obtained with a triggered phantastron as can be seen in figure IX.

If, during the linear downsweep of the plate, the grid resistor, R_1 is returned to a suitably negative potential with respect to the cathode, the oscillations will cease and the tube will operate as a DC amplifier with a similar feedback or error-reduction factor. The diode detector acts as a source of negative potential when it receives the proper control information from the discriminator amplifier. This then is the basis of locking the system.

In order to understand how the system operates a qualitative analysis of the circuit will be given. Assume that the transmitter is off so that no control information is reaching the diode detector and assume that the down sweep of the plate has started. This period is indicated by the region, A, in the plate wave form of figure IX.

At first the voltage drop across the resistor R_{g2} is negligible, first, because most of the current is reaching the plate and, second, because the value of R_{g2} is relatively small. As the plate potential approaches ground, more and more of the current flows through the screen because of its relative increase in potential over that of the plate.

*Essigman, M.W. (2)

With this increased screen current, the drop across R_{g2} will increase and therefore e_{g2} will start to fall. This drop of e_{g2} is coupled to the suppressor by means of the condenser C_2 which makes e_{g3} fall in potential and thus diverts more current to the screen producing a regenerative action at B.

As the suppressor is driven below ground reducing the plate current, the plate will rise. This rise, being coupled to the grid g_1 will cause more cathode current to flow, most of which will now be flowing to the screen. As these changes involve no changes in the charges on C_1 and C_2 , only the interelectrode and stray capacitances will slow it down and the transition will take place in a very few microseconds.

At this time, the rise in the plate potential will lift e_{g1} to a slightly positive value and grid current will be drawn thus preventing further rise in e_{g1} . At this instant the cathode current is large due to the positive bias, and the plate is cut off but is held close to ground by the condenser, C_{1g} . The screen grid, g_2 , is drawing the heavy current and therefore it is also close to ground. The suppressor will be below ground thus cutting off plate current.

During the next period, region C in figure IX, C_1 is charged with a time constant R_2C_1 towards Ebb and C_2 discharges toward ground with a time constant $(R_2 + R_{3a})C_2$. This process continues until the suppressor comes close enough to ground to allow some current to reach the plate which by this time is practically at Ebb. The flow of plate current at

this time starts the second regeneration.

The drop in e_p is coupled to the control grid, g_1 , which increases the bias and thus reduces the flow of cathode current. With less total current and increased plate current, the screen current is reduced and therefore the screen potential, e_{g2} rises. The rise in e_{g2} being coupled to e_{g3} , causes it to rise likewise and allows more current to reach the plate, lowering e_p and producing the switching action at D. The switching action stops when e_{g1} has been carried so far negative that the cathode current has been reduced to an amount consistent with the plate current required as C_2 discharges. This usually produces a drop of around ten volts.

Following the switching action, C_1 is discharged allowing e_{g1} to rise slowly with a time constant of $(R_1 + R_c + R_2)C_1$ which reduces the bias and allows more current to reach the plate and starts the linear down sweep again. Therefore the cycle of operations is complete. During the downward sweep C_2 charges and e_{g3} approaches ground again.

The action of the diode detector in search stopping is straightforward. During a positive pulse, the diode conducts and charges C_c through the diode resistance and the plate resistance of the video amplifier. When the pulse is removed, the charge remains and is slowly discharged through R_c and the video amplifier plate resistance. After a few pulses, the negative potential across the diode is large enough to stop the sweeping action of the transitron. The average charge on the diode will reach a negative value such that an

equilibrium condition obtains and the charge transferred by each pulse has the same magnitude as the charge leaking off between pulses.

When locked, the system reaches a stable equilibrium condition in which the oscillator rides far enough up the discriminator characteristic to supply pulses which give the correct bias to hold the repeller at the proper potential. The system is stable because, if the local oscillator frequency were to decrease, the pulse amplitude would decrease. The drop in repeller voltage would increase the frequency and counteract the original decrease of local oscillator frequency. Increasing the oscillator frequency would be compensated for in a like manner.

In the design of the circuit, there are a number of considerations. In the first place, R_4 and R_5 shunt the tube and therefore they should be large in order to reduce the loading on the plate. As the load is decreased, the range of the plate sweep is reduced. This is due to the increased current that flows through R_4 and R_5 which lowers the effective plate supply voltage. The voltage divider R_4 and R_5 also has one more adverse effect. If R_4 is made less than R_5 in order to increase the output variation, the range set control will be able to couple the negative supply to such an extent that at the low end of its travel it will force the plate of the tube negative thus cutting it off. If R_4 is made larger than R_5 this will not occur but a stepdown of the sweep occurs.

If the magnitudes of R_4 and R_5 are increased and made

too large, there is the possibility of reflector runaway in which the repeller becomes positive and emits electrons and thus prevents the high resistance voltage source from driving it back down into the negative region again. This limitation is, however, not critical as one half of the 6AL5 double diode is available to be used to prevent the repeller from becoming positive.

The extent of the sweep variation turns out to be about two thirds of the power supply voltage provided there is no load circuit. As soon as the load (R_4 and R_5) is added, the sweep at the plate is reduced and then it is further reduced by the voltage divider. With the values shown, the final sweep on the repeller is about one third of the total available power supply voltage.

R_{3A} is used to change the length of sawtooth sweep. By increasing its value, regeneration at point D can be made to occur sooner and thus reduce the amplitude of the sweep. If R_3 is made too small, there will not be enough voltage coupled to the suppressor and the circuit will not oscillate.

With the usual tubes R_3 should be from five thousand to twenty thousand ohms. With the new 6AS6 tube which was designed for use in phantastron circuits, R_3 would be so low that excessive screen current would be drawn before the circuit was operating properly. However, by forming a voltage divider of R_3 , increasing its size to about fifty thousand ohms and coupling only a small part of the screen voltage to the suppressor, the circuit will operate correctly without

excessive current drain by the screen.

To limit plate current and to provide high amplification, R_L should be made large.

Changing the value of C_1 changes the time of the sweep (region A) as it changes the discharge time constant of the grid circuit. R_2 should be large, around two megohms but if it is too large the sweep will miss a cycle or so.

R_1 should also be around the same size in order to limit the grid rise in a positive direction which would make the tube draw excessive current. R_c and C_c are chosen to have a time constant of several pulse intervals to provide some pulse integration. Normally R_c is the same as R_1 .

The hard tube diode transitron circuit has several advantages over the gas tube circuit. In the first place, although there is some ripple, it is very much less than that of the gas tube circuit. Using the values shown the ripple was less than one tenth of a volt.

In addition, the sweep is independent of the tube characteristics to a large degree and the sweep itself is much more linear than that of the gas discharge sweep.

Another advantage of the diode transitron is the fact that every pulse is used to give control information instead of a fraction of the number of pulses as in the gas tube circuit. This reduces the ripple considerably without decreasing the follow rate.

The circuit, however, has the disadvantage that it takes several pulses to build up enough charge on the coupling

condenser to lock the circuit in on the proper frequency. If the sweep rate is too high, enough charge will not accumulate before the sweep has passed the proper region. Under this condition, the system will never lock in, even though, if it were once locked in, it would stay there.

Wrong sideband elimination and control range are adjusted as in the gas tube by limiting the sweep range.

Because of the search and recycle provisions of the diode-transitron, the pull in range is equal to the hold in range which is an advantage over the previously discussed DC amplifier system.

The above circuit is the one with which I worked at Westinghouse Electric Corporation in Baltimore during the past term. With the component values as shown a sweep of sixty volts at a rate of two cycles per second was obtained. By means of the range set control, the sweep limits could be set from about twenty volts positive to one hundred and sixty volts negative.

f) Thermally tuned control circuit

The final general type of difference frequency AFC control circuit is the thermally tuned type, in this type geometric tuning is used instead of electronic tuning.

The reflex klystron tubes used are like other klystron tubes except for the method of tuning the cavity to the desired frequency. In these tubes a strut in the cavity is distorted by heat and the strut in turn alters the geometric configuration of the cavity and thus varies the frequency.

The strut is usually the plate of a small triode tube built into the klystron but electrically independent of it. The temperature of the strut is varied by changing the grid bias of the triode and thus the tube current and heat dissipation in the strut is likewise changed. This method of construction gives an extremely wide tuning range for thermally tuned tubes.

In this type of tube the large thermal tuning range gives rise to the problem of locking on to the proper sideband and rejecting the other sideband as the tubes will normally tune through both sidebands. In some thermally tuned circuits provision is made to lock properly to either sideband, whichever is the first one encountered.

In the previous types of circuits the frequency change was practically instantaneous with the applied control voltage. In the hunting systems it was necessary to limit the follow rate in order that the ripple on the repeller be reduced to a satisfactory value. In the thermally tuned system, the heat capacity of the tuning mechanism causes a delay between the application of the control voltage and the corresponding change in frequency. Consequently the ripple has no limitation on the follow rate and the limitation is solely due to this inherent time delay in distorting the strut.

Most thermal control circuits provide an on-off control. That is, the sweep is accomplished by alternately turning the power to the strut fully on and fully off at intervals long

enough to allow the oscillator to sweep through the required band. Locking is accomplished by having a switching rate so high that thermal inertia keeps the strut temperature substantially constant. The average temperature of the strut and consequently the frequency is determined by the duty ratio, that is, the ratio of the time spent with power on to the time spent with the power off.

For the fastest possible follow rates the power will remain either on or off until the desired point is reached. The position of the oscillator within the band will determine the maximum follow rates. Close to the edge of the band, the follow rate is high toward the center and low away from center.

The type of thermal control circuit to be discussed is the Whitford control circuit developed by A. E. Whitford of the Radiation Laboratory. It is a single flip flop system in which the circuit locks on only one sideband and rejects the other.

Figure X shows a block diagram of the Whitford system and figure XI gives the schematic diagram of the circuit. Referring to the block diagram the special coupling circuit provides circuits which will allow positive pulses from the discriminator to turn the strut power on and for negative pulses to turn it off. When the power is off, the frequency increases and when power is on the frequency decreases.

With power on and the frequency decreasing, the local oscillator frequency will move to the left (see drawing XII) until it comes to the upper sideband. At this point the

discriminator action will send positive pulses which will have no effect as the power is already on. The frequency will then continue to decrease until crossover is reached. At this time the discriminator pulses will be negative thus turning off the strut power and reversing the direction of travel of the local oscillator. With the power off the frequency will increase until the positive pulses are again generated and the frequency will lock in on the upper sideband.

If the system contained only the above provisions, it would be possible for the local oscillator to become trapped between the lower limit of the sweep and the positive part of the lower discriminator band. Every time the power was off and approached the lower sideband from below, positive pulses would send it back toward the lower frequencies. To get out of this trap the tuning multivibrator desensitizes the video amplifier when power is off so that no pulses can get through to the heat control multivibrator and effect its operation.

The main purpose of the timing multivibrator is to turn the heat control on and off in the absence of discriminator output, so the local oscillator will hunt back and forth across the band. When the system is locked on the proper frequency, the locking tube cuts off this timing multivibrator and prevents it from operating the on-off heat control.

The heat control multivibrator simply turns the strut power on or off in obedience with the received pulses.

The actual schematic diagram of the Whitford control circuit will now be discussed so that the method of obtaining the required signals can be understood.

The circuit which controls the power to the tuning strut is the heat control multivibrator V_{4a} and V_{4b} . This circuit is a one shot Eccles-Jordan multivibrator and has two stable conditions of equilibrium. When one section is on the other section is off. When V_{4a} is off its plate will be at B+ and because of the voltage divider to the negative supply, the triode tuner grid will be close to ground. This will allow the triode tuner to conduct and apply heat to the strut thus reducing the local oscillator frequency. In the other condition V_{4a} is conducting and V_{4b} is off. The plate of V_{4a} is lowered to a potential close to the cathode potential and the tuner grid is negative and well below cutoff. The local oscillator frequency will then increase.

With the power on, the frequency will decrease until it reaches the upper sideband at which time positive pulses will appear at the grid of V_1 . These pulses are amplified and inverted by V_1 and applied to the grid of V_2 . The output of V_2 will then be a negative pulse at the cathode of V_{3a} and a positive pulse at the cathode of V_{3b} . V_{3b} will not conduct and the positive pulse will not get through to the heat control multivibrator.

The negative pulse on V_{3a} will cause the diode to conduct and apply the pulse to the grid of V_{4a} . As V_{4a} was already off, this pulse will have no effect and the frequency will

continue to decrease. After crossover is passed, negative pulses will be generated by the discriminator and pass through the same chain to give a negative pulse at the grid of V_{3b} . The pulse will pass through the diode and be applied to the grid of V_{4b} . As V_{4b} was on, this pulse will cut it off and thus cut on V_{4a} . When V_{4a} is turned on, the plate drops so that strut power is cut off. The local oscillator will then increase the frequency back toward crossover and the system will lock in as described before.

Hunting and desensitizing as previously discussed are accomplished in the timing multivibrator. This is a free running plate coupled multivibrator whose period is slow enough so that the local oscillator can sweep through the required band.

The grid wave form of V_{5a} is such that the grid potential is at ground when the tube is conducting and it is negative and rising exponentially when V_{5a} is not conducting. A lead from the grid of V_{5a} goes to the suppressor grid of V_1 . As long as the grid of V_{5a} is close to ground, V_1 acts as a normal amplifier but when V_{5a} is cut off and its grid is negative, the suppressor is likewise negative and cuts off V_1 so that no pulses can get through. This provides the required desensitizing as previously mentioned.

It is necessary to investigate the action of the timing multivibrator in shifting the strut power on and off. When V_{5a} is cut off a sharp negative wave appears at the suppressor of V_1 . This wave cuts V_1 off and produces a positive pulse

at the plate which turns V_{4b} off and V_{4a} on thus cutting off strut power. The circuit then will be desensitized when strut power is off which was originally required to prevent the sweep from being trapped.

This condition will continue until the timing multivibrator turns over and sharply cuts V_1 on again. This will produce a negative pulse at the plate of V_1 which will cut off V_{4a} and turn on strut power. Therefore the hunting feature of the system is provided for.

When the system is locked, it is not desired to have the timing multivibrator operate and unlock the local oscillator. To block the operation of the timing circuit coupling is provided from the plate of V_{4b} through a diode V_6 to the grid of V_{5b} .

When the system is locked and the heat control multivibrator is oscillating rapidly, a square wave will be generated by V_4 . The diode V_6 will then rectify this wave into a negative potential which will bias V_{5b} off and prevent the tuning multivibrator from functioning.

From the above discussion it can be seen that the thermal tuned control circuit is much more complicated than the circuits previously covered. However, there are a number of advantages gained by this type.

First they will allow fully automatic following of the transmitter over a wide range and may allow the operator to escape enemy jamming. A second point in its favor is that with the use of low IF frequencies it provides a positive

method of locking on the correct sideband and rejecting the wrong one. In addition the circuit is very reliable and is not critically dependent on tubes or components.

V ABSOLUTE FREQUENCY AFC SYSTEMS

The second main classification of AFC systems is the Absolute Frequency AFC. In this system the local oscillator is maintained at a given frequency. In radar sets absolute frequency systems are used with beacon receiving systems which involves a number of considerations that did not exist for difference frequency systems.

In the first place, the beacon problem is different from the normal echo receiving radar. In a beacon system there is no signal present in the radar set at the proper frequency until the desired pulse from the beacon is received. Therefore the AFC system must be such that the system is always in tune to the beacon while awaiting the signals.

If the beacon signals were received continuously at the radar receiver, they could be used to cause an AFC system, similar to those previously described, to lock on the proper frequency. However, because of antenna scanning, only a few groups of pulses are available at each rotation of the antenna.

Because of the fact that there is no sample of the transmitter frequency continuously available at the receiver, the problem of manually tuning the receiver to the proper frequency becomes very difficult making an AFC system highly desirable. With either manual or automatic frequency control it becomes necessary to know the beacon frequency. For this reason beacons used for a given type of service operate at a single fixed frequency.

a) Electronically tuned system

There are two main types of control systems in use with absolute frequency AFC systems. The first type is tuned by electronic means and the second by changing geometric factors. In the first type tuning is accomplished as in the first three difference frequency systems by changing the repeller potential of a reflex klystron. The second type tunes a thermally tuned klystron.

A block diagram of an electronically tuned absolute frequency system is shown in figure XIII. In this system an audio oscillator puts a low voltage signal of about one half of a volt rms at around a thousand cycles per second on the repeller of a klystron. The output of the klystron will be a frequency modulated signal around the frequency determined by the DC level of the repeller. The output of the local oscillator then goes through a precision cavity and is rectified in a crystal detector.

The precision cavity is loaded by the crystal and the local oscillator until its bandwidth approximates the locking accuracy that is desired. Since the audio modulating voltage is small, the local oscillator power output is substantially constant and the crystal output versus local oscillator frequency produces a curve that is nearly the same as the loaded resonance characteristic of the cavity.

Referring to figure XIV, the output of the crystal detector is shown under its operating conditions. When the local oscillator is operating on one side of this resonance characteristic, the output of the crystal will be in phase with the

audio oscillator. When the local oscillator is operating on the other side of the characteristic, the crystal output voltage will be 180 degrees out of phase with the audio oscillator. This reversal of phase may be likened to the output of a discriminator and is used to control the gas coincidence tube.

The coincidence tube is a 2050 or a 2D21 gas tube. Experiments on these types of tubes have shown that if either grid is biased to minus ten volts, it will take at least seventy five volts on the other grid to fire the tube. This property is used to advantage in the coincidence tube circuit. Each grid is biased at minus ten volts and the output of the audio oscillator is coupled to one grid with the output of the crystal detector amplifier coupled to the other. The amplitudes of the two signals are adjusted so that they are large enough to fire the tube when the two waves are in phase but are not large enough to fire the tube when they are out of phase.

When the gas discharge tube fires, since the condenser, C, cannot discharge instantaneously, the voltage across the cathode resistor rises close to plate potential and then decays through the cathode resistor and tube resistance as the condenser discharges. If a diode transitron is used as the control circuit, this positive pulse acts in the same manner as the positive discriminator pulse in stopping the sweep and locking on to the correct frequency.

The system is stable, for, if the local oscillator de-

creases in frequency, the grid voltages on the coincidence tube will be out of phase. This will stop the coincidence tube from firing and allow the negative bias on the transitron to leak off permitting more plate current to be drawn. The increase in plate current in the transitron plate load resistor will lower the plate potential and thus increase the frequency.

If the frequency increases, the grid voltages will be in phase, permitting the coincidence tube to fire at the audio oscillator rate. This will develop more bias on the transitron which reverses the previous situation and decreases the frequency.

This type of automatic frequency control can be used with a gas discharge type control circuit. In this case the diode transitron is replaced by the sawtooth generator of the gas tube circuit and the coincidence tube takes the place of the search stopping tube.

b) Thermally tuned circuit

One type of thermally tuned AFC circuit was devised by W. Strandberg of the Radiation Laboratory and is shown in figure XV. In this circuit V_1 and V_2 are audio amplifiers with a low frequency response down to a fraction of a cycle. V_3 is a cathode coupled multivibrator. V_4 and V_5 form the heat control circuit and V_6 is a transitron oscillator.

When the circuit is first turned on, the left hand side of V_3 is biased to cutoff by the cathode current in the right hand side of the tube drawing current and producing a positive potential on the common cathode.

The sweep in frequency is generated by negative pulses from the transitron oscillator V_6 . These negative pulses are coupled through the diode V_4 to the grids of V_5 which is a plate coupled multivibrator. Whichever side of V_5 that had been conducting will be turned off by the negative pulses, positive pulses from the transitron oscillator will have no effect as they cannot get by the diode V_4 . When the right hand side of V_5 is conducting, its plate will be low and slightly above ground. The tuning grid will then be biased negatively and power to the strut will be off. When the right hand side of V_5 is cut off its plate will be high and the voltage divider to the negative supply will be such that the tuner grid will be close to ground. This will allow the strut tuner power to be on and the frequency will be lowered, thus providing the required sweep across the proper spectrum.

As the strut sweeps the frequency to the cavity resonance curve a sharp rise in the crystal current will occur. This current will develop a positive sloped voltage wave at the grid of V_1 . The audio amplifiers V_1 and V_2 will amplify the positive wave and apply it to the grid of V_3 thus turning it on.

The regenerative action of the left hand side of V_3 cutting on will cut off the right hand side of V_3 and produce a positive pulse on the cathodes of V_4 . Being a positive this pulse will have no effect on the heat control multivibrator and the local oscillator will continue to sweep in the same direction.

As soon as the local oscillator frequency passes the peak of the cavity response, the current will drop in the crystal and produce a negative wave on the grid of V_1 . This wave will have the opposite effect from the first pulse. It will cut off the left hand side of V_3 and cut on the right hand side, producing a negative pulse on the plate of the right hand side of V_3 and consequently a negative pulse on the grids of V_5 .

Whichever section of V_5 that had been on will then be cut off and strut power will be reversed.

The reversal of strut power will cause the local oscillator to reverse its direction back toward the hump of the cavity response curve thus producing the original effect of turning on the left hand side of V_3 so that it is once more ready to reverse the sweep after the peak is passed.

The total effect of these actions is to have the local oscillator ride back and forth across the peak of the cavity response curve and lock on at the proper frequency as determined by the setting of the precision cavity.

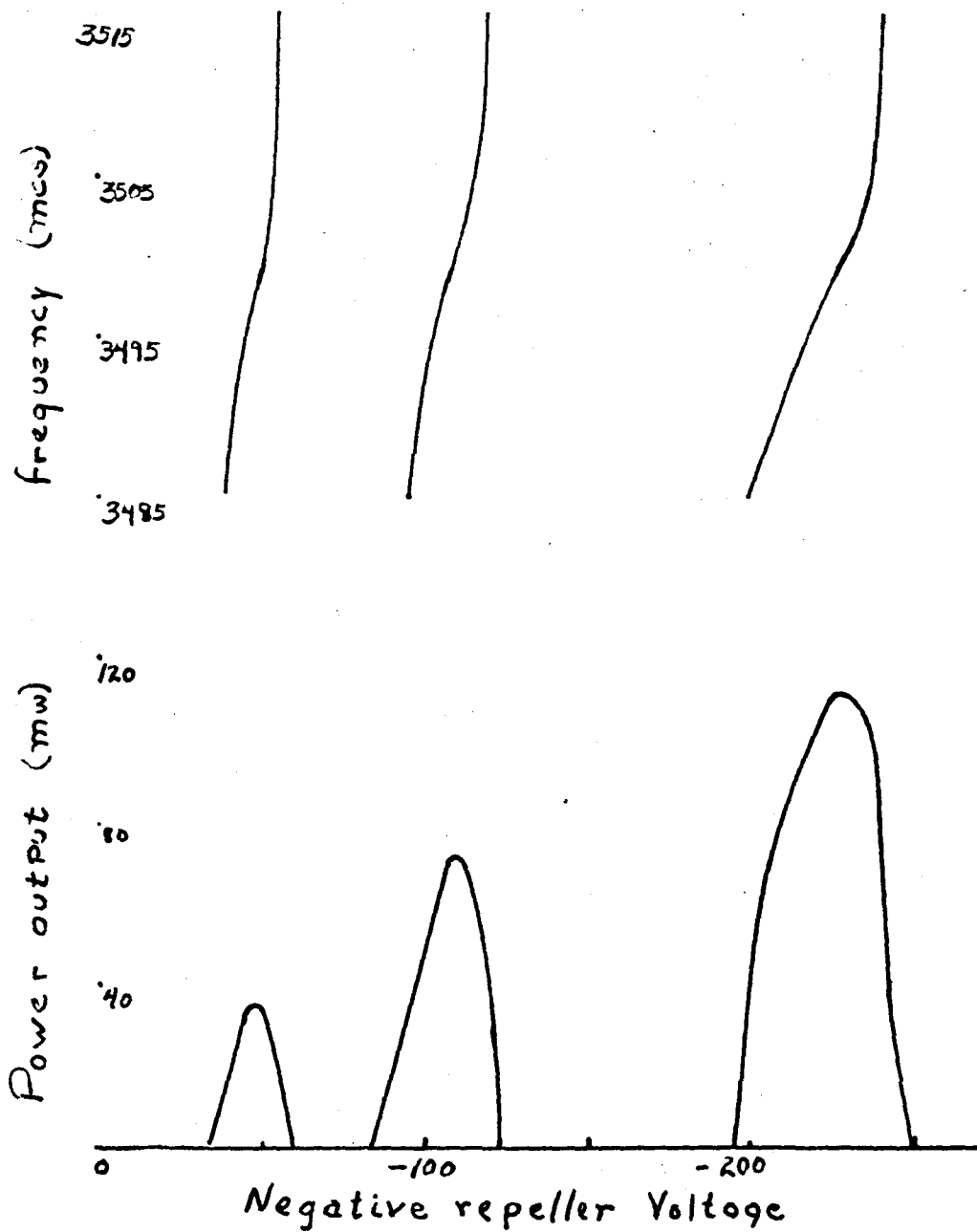
The transitron oscillator does not have to be blanked off when the system is locked as any information it sends to the heat control circuit will be changed by the effect that this information produces.

The above circuit has the disadvantage that it is subject to false signals in the form of hum or microphonics. If a signal was received at the left hand grid of V_3 before the peak was passed but after resetting had occurred, it would

reverse the heat flow too soon and unlock the system. For this reason the circuit is not considered too reliable and development of a more suitable system is being investigated at the present time.

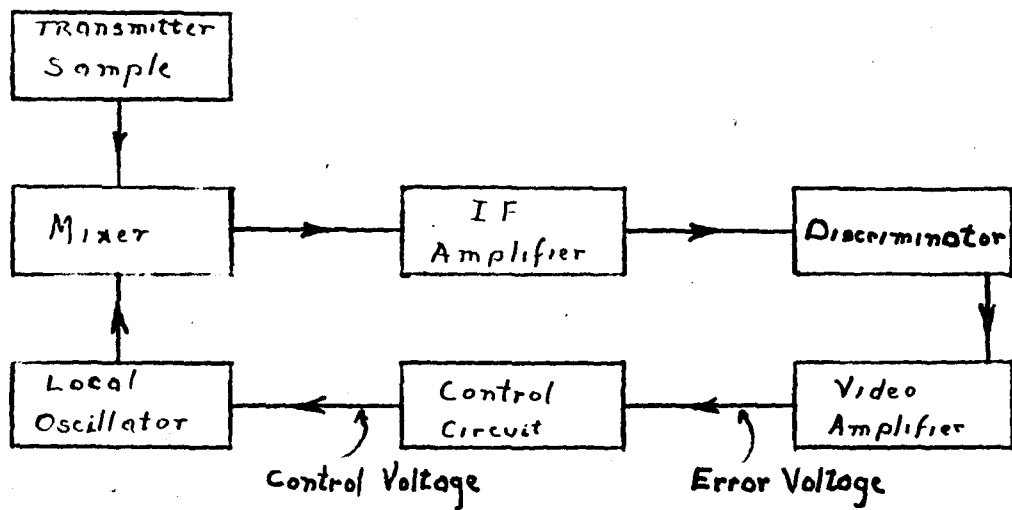
BIBLIOGRAPHY

1. Bode, H.W. Network Analysis and Feedback Amplifier Design, New York, Van Nostrand, 1945.
2. Essigman, M.W. Analysis of the Operation of the Basic Phantastron Circuit. MIT Radar School Staff, 1947.
3. Fisk, J.B., Hagstrum, H.D. and Hartmen, P.L. The Magnitron as a Generator of Centimeter Waves. BSTJ April 1946.
4. Nyquist Regeneration Theory, BSTJ January 1932.
5. Pierce, J.R. and Shepard, W.G. Reflex Oscillators BSTJ July 1947.
6. Pound, R.V. and Eric Durand Microwave Mixers, New York. McGraw-Hill 1948.
7. Strandberg, W. Automatic Frequency Control of Thermally Tuned Beacon Local Oscillator Cambridge Radiation Laboratory Report #955 1946.
8. Terman, F.E. Radio Engineers Handbook New York McGraw-Hill 1943.
9. Van Voorhis, S.N. Microwave Receivers New York McGraw-Hill 1948.



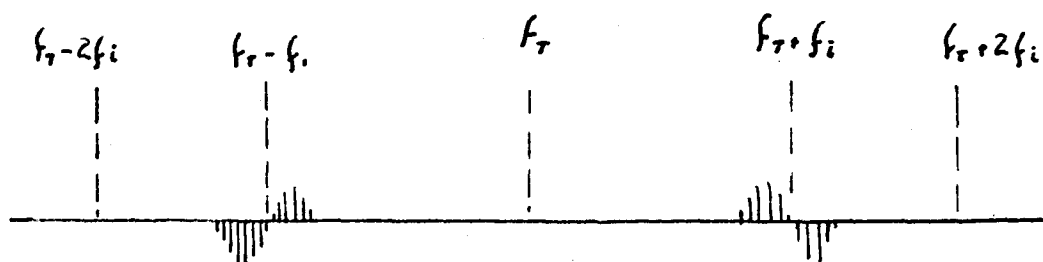
REFLEX - KLYSTRON CHARACTERISTICS
(Spongenberg)

FIGURE I



BLOCK DIAGRAM OF AFC LOOP

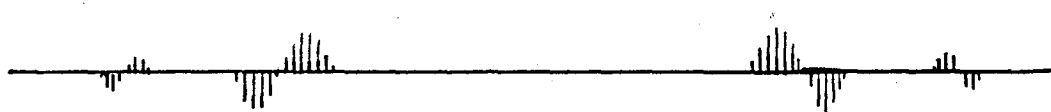
FIGURE II



Pulsed transmitter, no spurious signals.



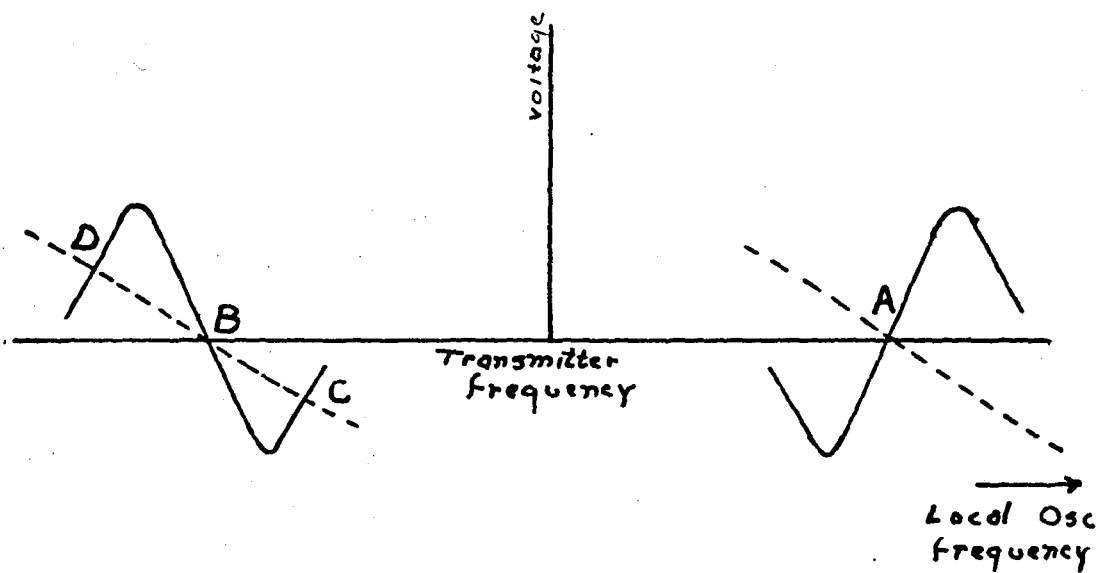
Pulsed transmitter, shock excitation only



Pulsed transmitter, harmonic signal only

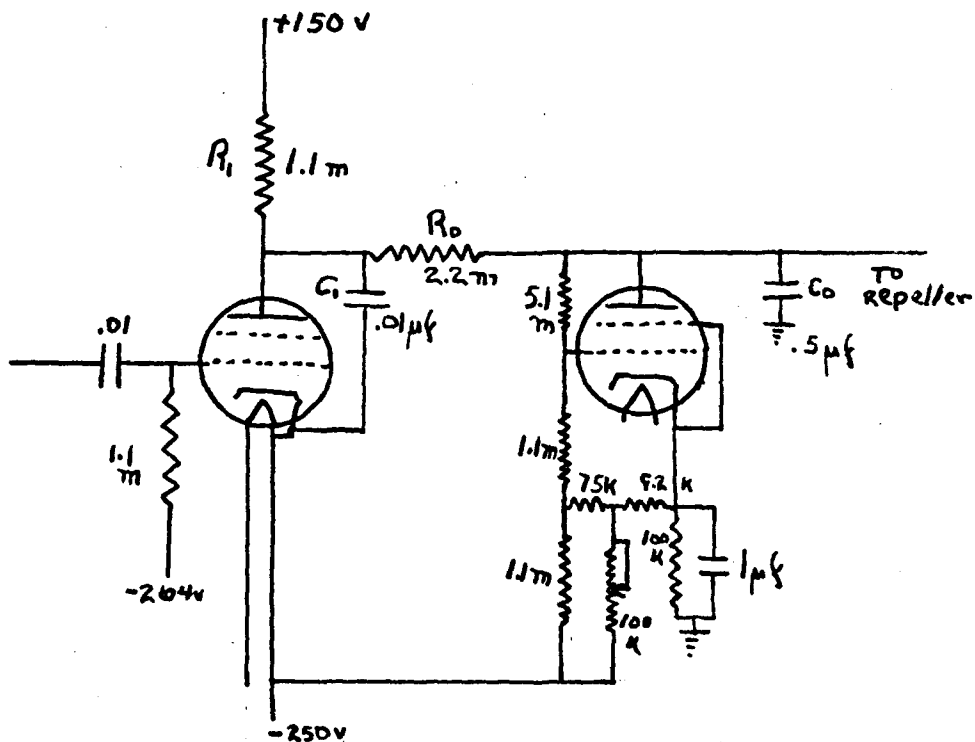
f_T - transmitter frequency
 f_i - intermediate frequency

FIGURE III



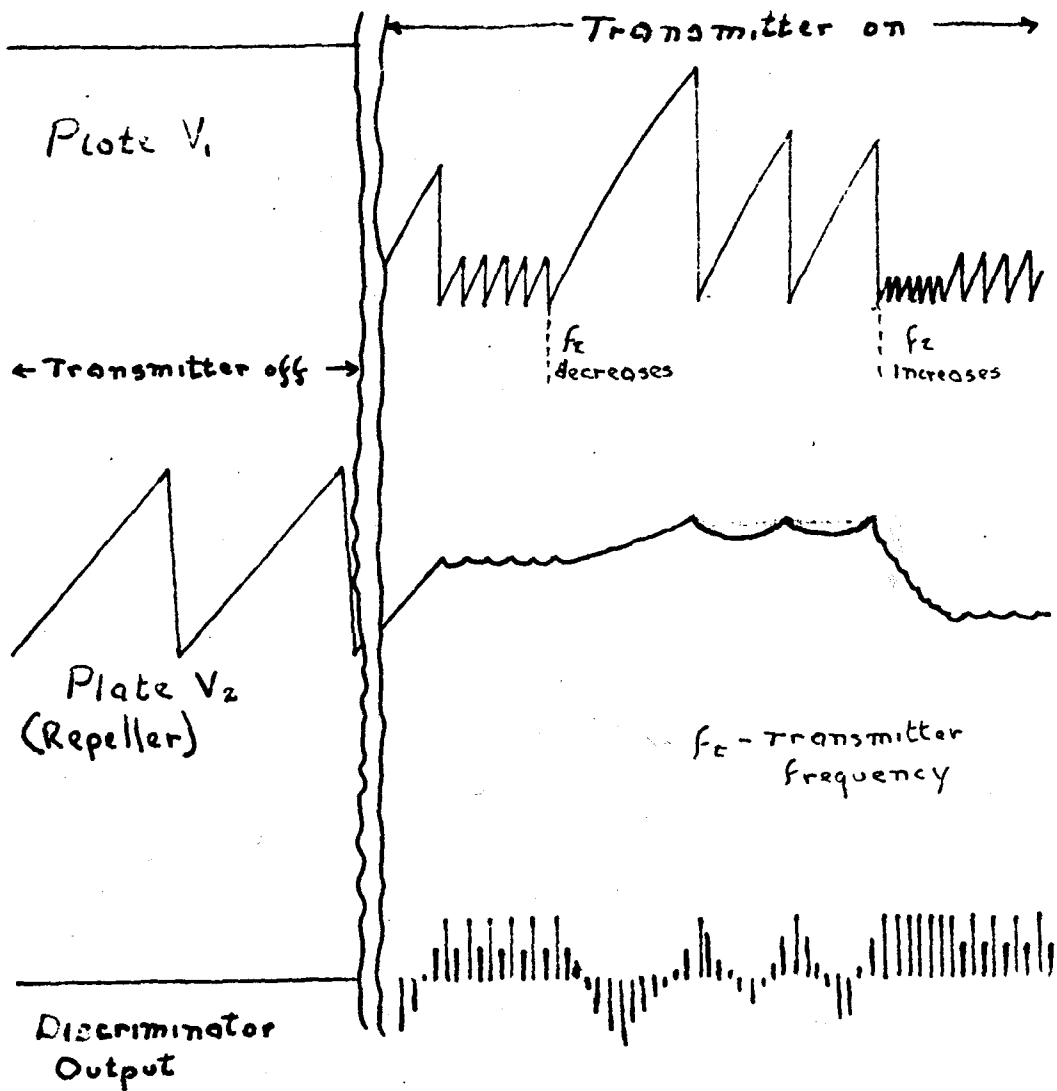
WRONG SIDEBAND EFFECT

FIGURE IV



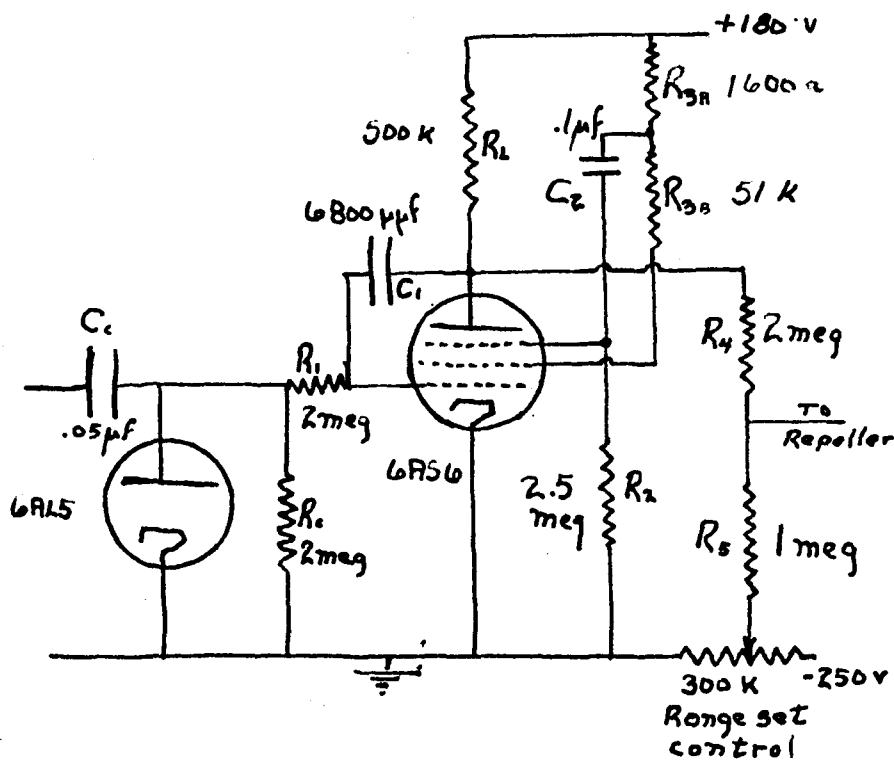
Gas tube AFC (Westinghouse)

FIGURE VI



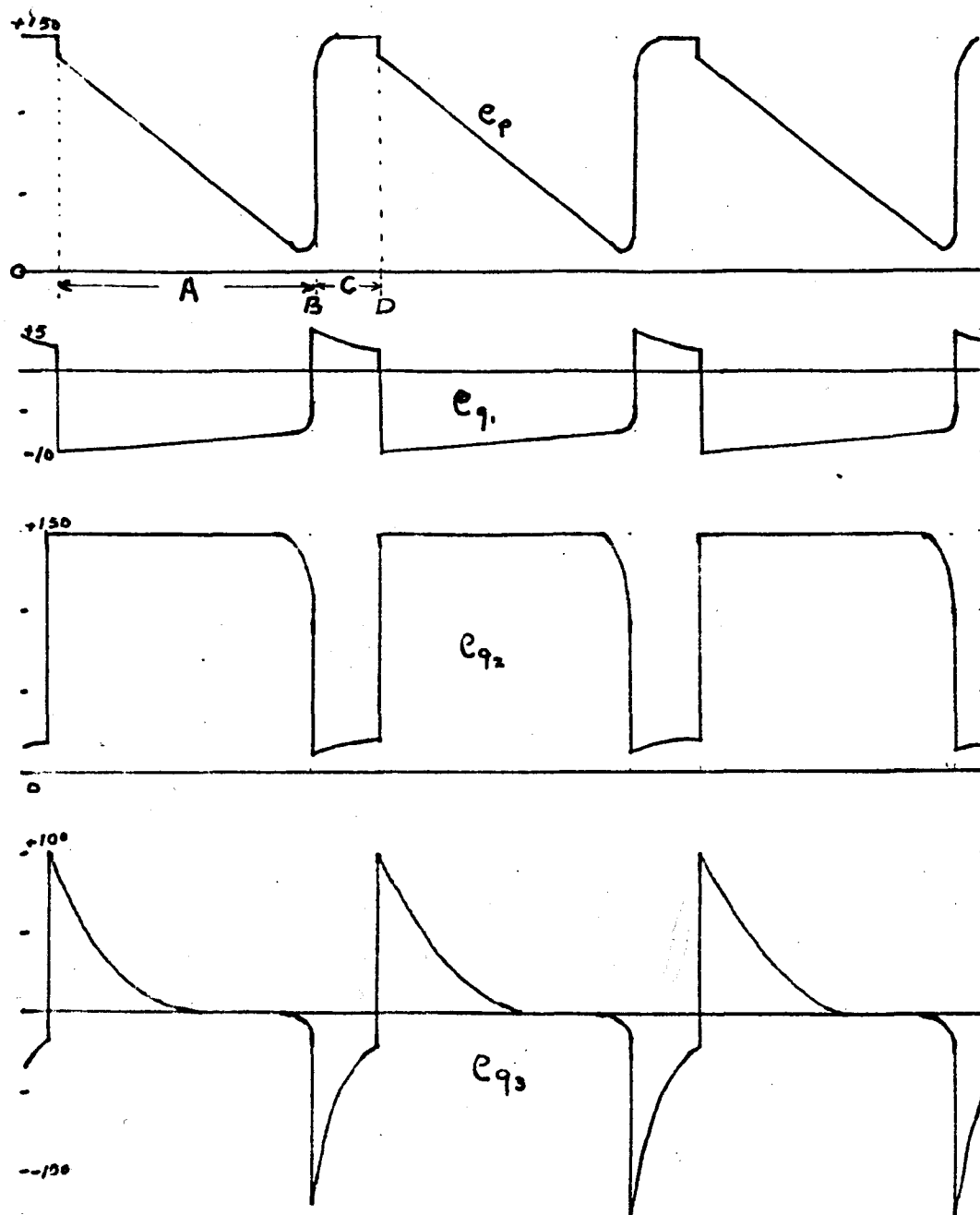
Gas Tube AFC Waveforms

FIGURE VII



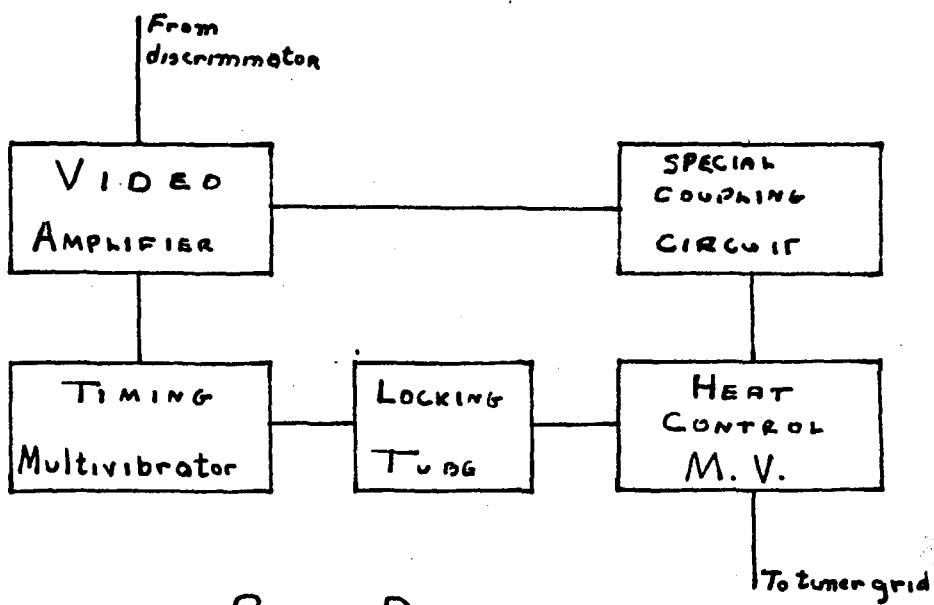
DIODE TRANSISTRON CONTROL CIRCUIT

FIGURE VIII



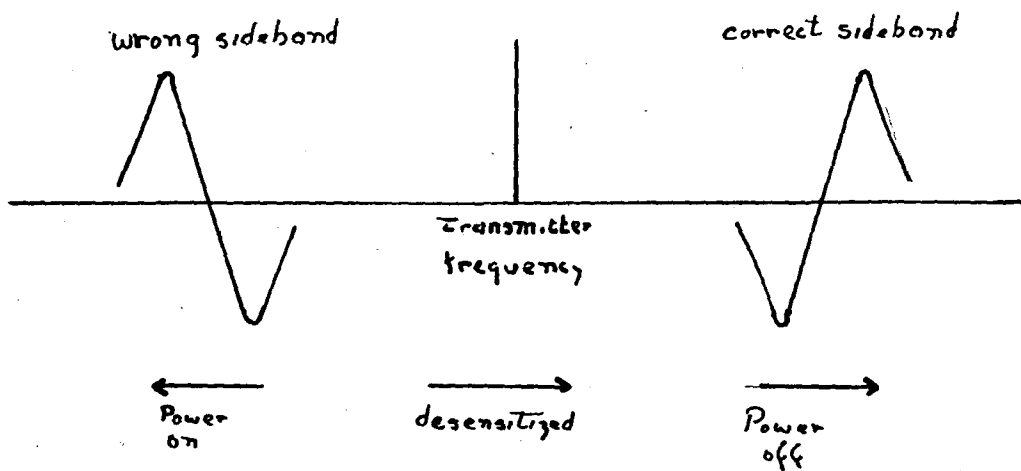
DIODE-TRANSITRON WAVEFORMS

FIGURE IX



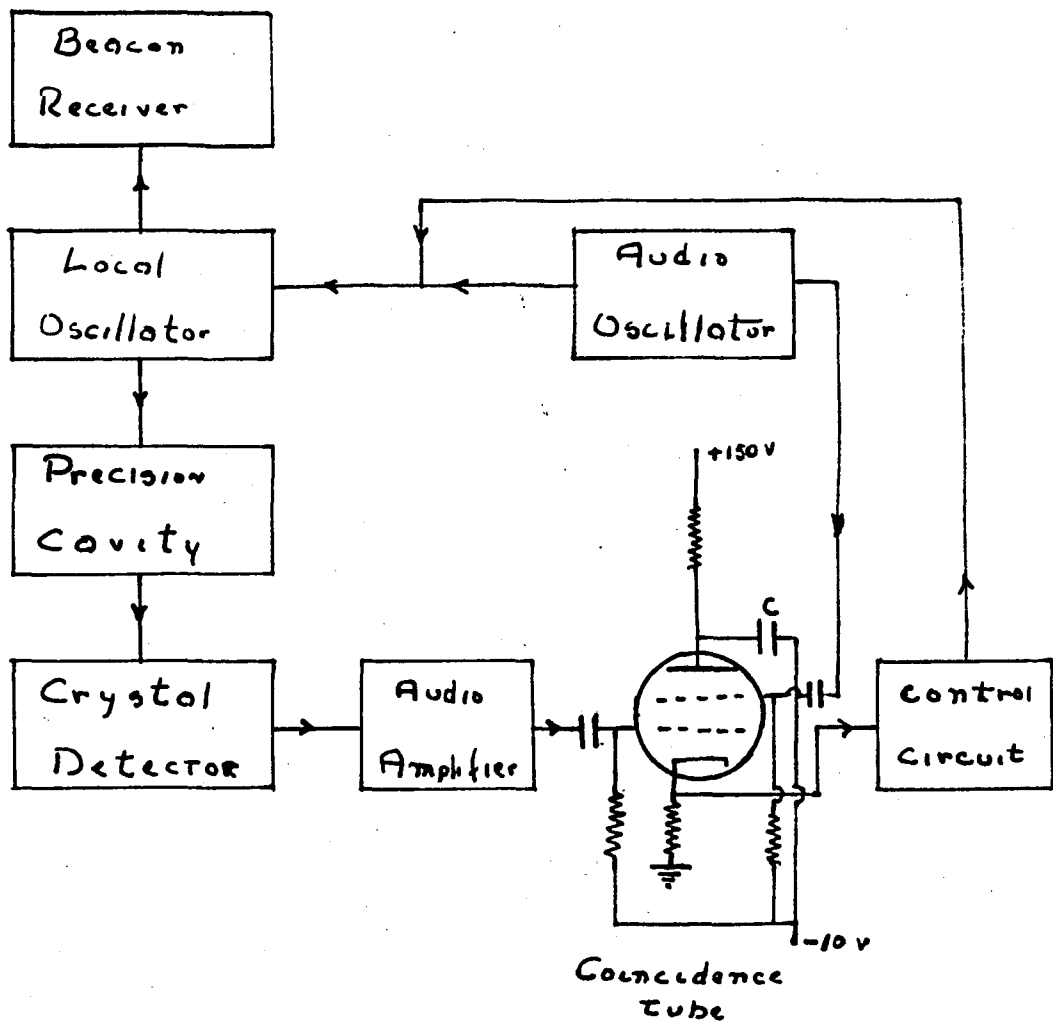
BLOCK DIAGRAM
WHITFORD AFC

FIGURE X



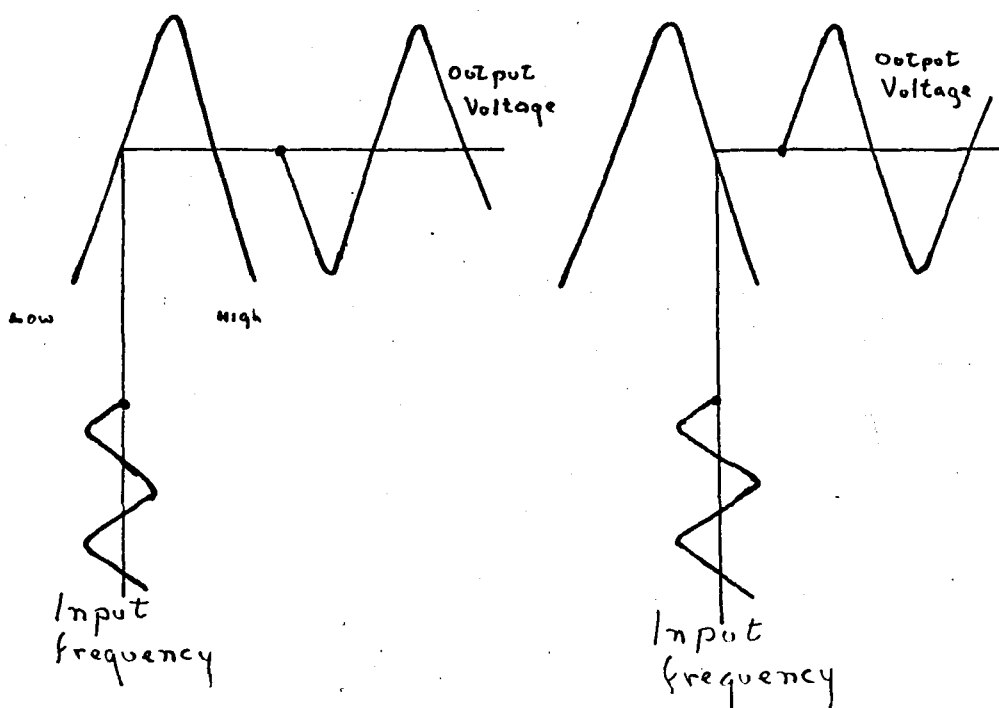
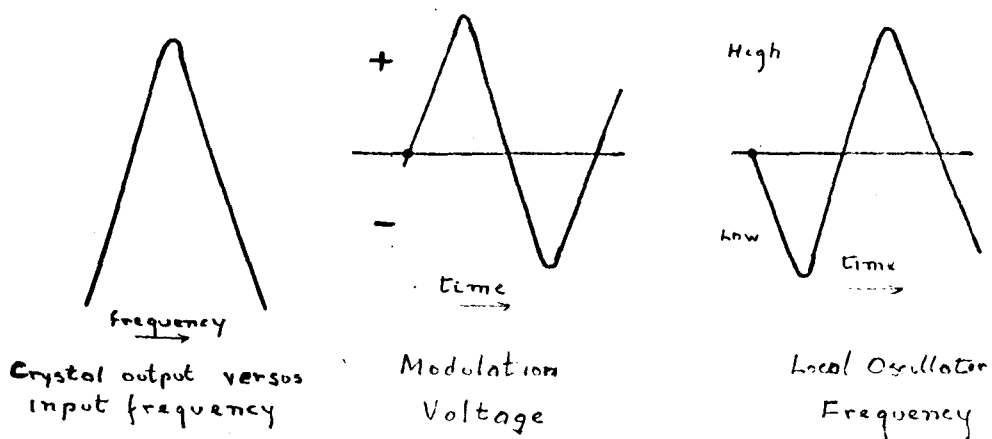
DISCRIMINATOR CHARACTERISTIC
WHITFORD AFC

FIGURE XII



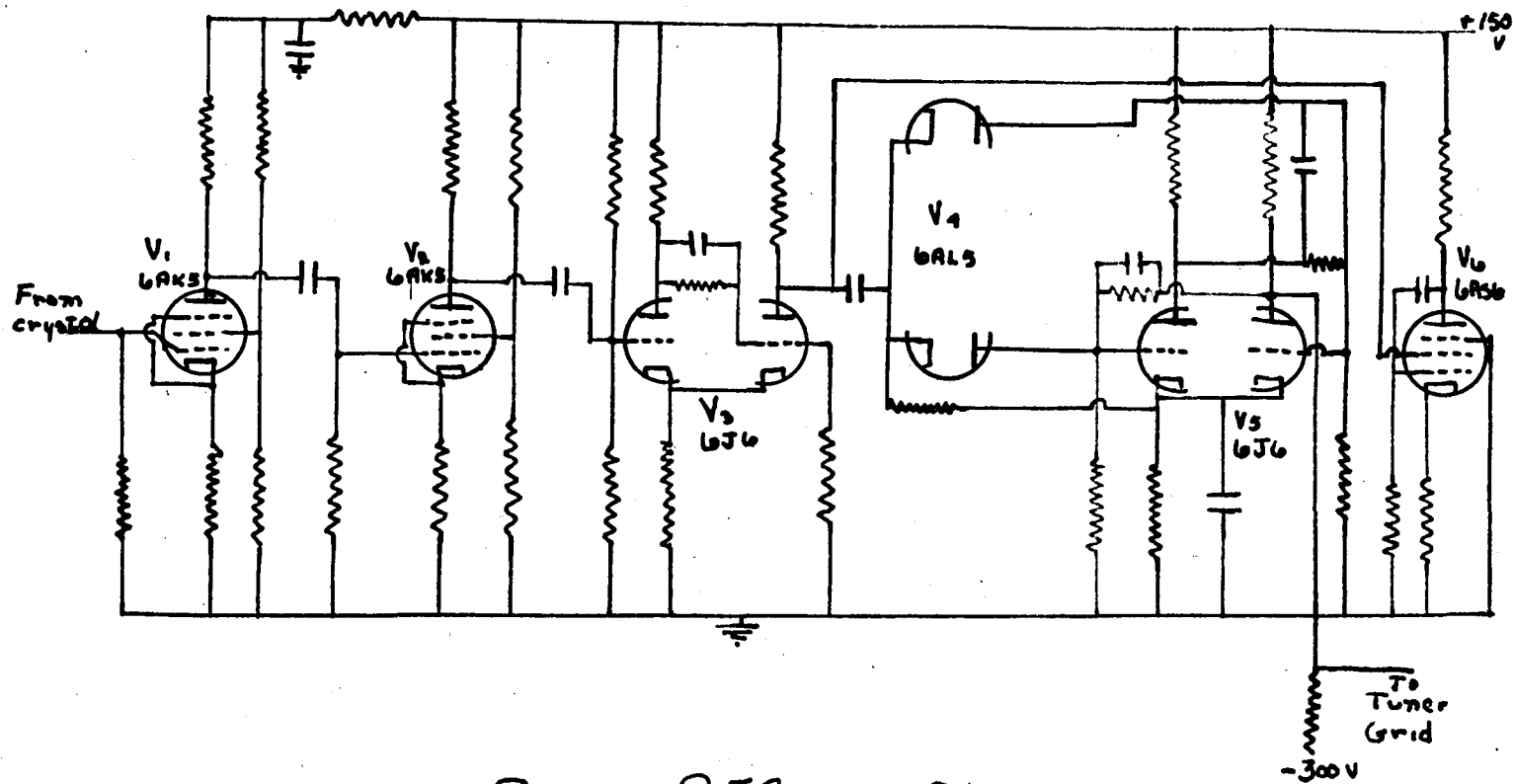
ABSOLUTE FREQUENCY AFC, BLOCK DIAGRAM

FIGURE XIII



ABSOLUTE FREQUENCY AFC WAVEFORMS

FIGURE XIV



BEACON AFC FOR 2K45

FIGURE XV